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Devoted to All Branches of Optics

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JANUARY-MARCH 1919

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and Applied Optics

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This Journal is the official organ of the Optical Society of America. It was founded to redeem the constitutional pledges of the society to promote the spirit of coöperation among workers in all branches of optics and coördinate the results of their labors.

To that end it publishes:

1) Original articles;
2) Short abstracts of articles of interest which have appeared in other journals;
3) Abstracts of patents;
4) The proceedings of the Optical Society of America and notes on the activities of local sections.

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Journal

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AND APPLIED OPTICS

Volumes II-III JANUARY—MARCH, 1919 Numbers 1 and 2

WAR-TIME DEVELOPMENT OF THE OPTICAL INDUSTRY[1]

By Major Fred E. Wright

Pre-War Conditions

The optical industry in this country before the war was in the hands of a few firms. Several of these were under German influence, and one firm was directly affiliated with the Carl Zeiss Works of Jena, Germany; the workmen were largely Germans or of German origin; the kinds and design of apparatus produced, were for the most part essentially European in character; optical glass was procured entirely from abroad and chiefly from Germany. It was easier and cheaper for manufacturers to order glass from abroad than to develop its manufacture in this country. Educational and research institutions obtained a large part of their equipment from Germany and offered no special inducement for American manufacturers to provide such apparatus. Duty-free importation favored and encouraged this dependency on Germany for scientific apparatus.

[1] Presented at the meeting of the Optical Society of America held on December 29, 1918 at Baltimore, Md.

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WAR-TIME CONDITIONS

With our entrance into the war, the European sources of supply for optical glass and optical instruments were cut off abruptly and we were brought face to face with the problem of furnishing these items in large quantities to the Army and Navy for use in the field. Fire-control instruments, such as range finders, panoramic sights, battery commander telescopes, field glasses, are exceedingly important items in military field operations, because by them much of the firing, especially by the artillery, is directed and controlled. The gunner who cannot see to aim correctly is unable to place his shots effectively and is at a serious disadvantage in the presence of the enemy. If the Army and Navy were to have these instruments when they needed them, it was essential that they be manufactured in this country, and that production on a very large scale be pushed rapidly and effectively.

Such was the situation in April, 1917. The fundamental item for these instruments, optical glass, had not been produced satisfactorily in quantity in this country. The methods for its manufacture on a large scale had first to be developed; after the supply of optical glass had been assured, the manufacturing capacity for precision optics had to be increased on a scale commensurate with the needs; and finally the design of new instruments required proper supervision with reference both to ultimate field use and to speed of production.

MANUFACTURE OF OPTICAL GLASS

Before this country entered the war, it was realized that the making of optical glass might prove to be a serious problem. Prior to 1914, practically all of the optical glass used in the United States had been imported from abroad; manufacturers followed the line of least resistance and preferred to procure certain commodities, such as optical glass, chemical dyes, and other materials difficult to produce, direct from Europe, rather than to undertake their manufacture here. The war stopped this source of supply abruptly, and in 1915 experiments on the making of optical glass were under way at five different plants: The Bausch & Lomb Optical Co. at Rochester, N. Y.; the Bureau of Standards at Pittsburg, Pa.; the Keuffel & Esser Company at Hoboken, N. J.; the Pittsburg Plate Glass Company at Charleroi, Pa.; the Spencer Lens Company at Hamburg, Buffalo, N. Y.

By April, 1917, the situation had become acute; some optical glass of fair quality had been produced, but nowhere had its manufacture in adequate quantities been placed on an assured basis. The glass-making processes were not adequately known. Without optical glass, fire-control instruments could not be produced; optical glass is a thing of high precision, and in its manufacture, accurate control is required over all the factory processes. In this emergency the Government appealed to the Geophysical Laboratory of the Carnegie Institution of Washington for assistance. This laboratory had been engaged for many years in the study of solutions, such as optical glass, at high temperatures, and had a corps of scientists trained along the lines essential to the successful production of optical glass; it was the only organization in the country with a personnel adequate and competent to undertake a manufacturing problem of this character and magnitude. A group of their scientists, with the writer in charge, was accordingly placed in April, 1917, at the Bausch & Lomb Optical Company, and took over virtual direction of the plant; its men were assigned to the different factory operations and made responsible for them. At this plant, much of the pioneer development work was accomplished; the methods of manufacture on a large scale were here developed and placed on a production basis. In the early months of the war, Mr. Victor Martin, a practical glass worker, who had been experimenting since 1912 at this plant, rendered exceedingly valuable aid and co-operated heartily in the solution of the difficulties.

The search for raw materials of adequate purity in ton lots, the preparation and mixing of the batches, the control of the melting furnaces, of the pot arches, and of the annealing ovens, the stirring of the molten glass, the inspection of the product at the several stages, these and other problems had to be studied in detail, and in each case, exact information gained regarding the best practice to be followed; this was then adopted. Soon after our arrival at the plant, it was the writer's good fortune to discover, as a result of a statistical study of the existing chemical analyses of glass, certain relations which enabled us to write down at once the batches for glasses, especially in the flint series, of desired optical constants. This discovery freed our minds of the uncertainty regarding our ability to reproduce optical glasses of standard types, the batches of which were held secret by glass makers. Additional studies and analyses made at the Geophysical Laboratory have borne out the conclusions deduced from these preliminary studies.

By November, 1917, the manufacturing processes had been mastered, and optical glass was being produced at this plant on a large scale, and of a quality comparable to the European product. Since that time the quality has steadily improved. The glass which is now made at several plants in this country is equal to the best European product. In December, 1917, the work was extended and men from the Geophysical Laboratory took practical charge of the plants of the Spencer Lens Company and of the Pittsburgh Plate Glass Company.

In addition to the above makers, optical glass was produced by the Keuffel & Esser Company in quantities sufficient to supply their own needs. Much credit is due to Mr. Carl Keuffel who, on his own initiative and before we entered the war, erected a glass melting furnace, made suitable pots, and produced some glass of good quality without any outside help.

Small quantities of optical glass were also produced in furnaces at the Bureau of Standards at Pittsburgh. Dr. Bleininger developed at this plant a poured, porcelain-like crucible which promises to be satisfactory for use with the dense barium crown melts that attack ordinary clay pots vigorously,

In the solution of the optical glass problem, the contribution of the Geophysical Laboratory to the Government amounted to about two hundred thousand dollars, but the results attained justified these expenditures. These results could not have been attained, however, without the hearty and patriotic co-operation of the manufacturers and of the Army and Navy. The Bureau of Standards aided in the development of a chemically and thermally resistant crucible in which to melt optical glass; also in the testing of optical glass and especially in the testing of optical instruments. The Geological Survey aided in locating sources of raw materials, such as sand, of adequate chemical purity.

MANUFACTURE OF OPTICAL INSTRUMENTS

By February, 1918, the supply of optical glass was assured; but the manufacture of optical instruments was so seriously behind schedule that a Military Optical Glass and Instrument Section was formed on the War Industries Board to take control of the entire optical instrument industry of the country; of this section, Mr. G. E. Chatillon, of New York, was appointed chief, and Commander W. R. Van Auken and Major F. E. Wright, Navy and Army representatives respectively. The section was charged with the responsibility of developing the manufacturing capacity

of the country to meet the needs of the Army and Navy in fire-control instruments. To do this, it was necessary that existing factories be enlarged, and that manufacturers who had had no experience in precision optics be encouraged to enter the field as a patriotic duty, and to have assigned to them orders which they would, within reasonable time, be able to fill.

Because of the very large demands of the Government for both optical glass and optical instruments, it was found necessary for the Military Optical Glass and Instrument Section of the War Industries Board to assume control of the entire optical glass and fire-control instrument industry, and, by a system of permissions, to scrutinize the entire output. Commercial orders were rigidly restricted; requests for priority were passed upon. The optical glass as produced was controlled and distributed by the section to the several departments of the Army and Navy and to manufacturers having direct Government contracts. Through the direct control of the optical glass industry, the optical instrument industry was easily regulated, and its output directed chiefly to Government channels. In conjunction with the War Trade Board, the Optical Section passed upon applications for both import and export licenses, and for materials affecting the optical industry.

At the time of the signing of the Armistice, the manufacturing capacity of the country had been developed to such an extent that the requirements of the Army and Navy were not only being met in most instances, but the greatly increased requirements for the large armies of 1919 were assured.

At the outbreak of the war, the policy followed by the Government was to place orders for standard optical apparatus, such as range finders of different base lengths, battery commander telescopes, aiming circles, panoramic sights, muskets sights, field glasses, microscopes, with firms of established reputation and experience. The result was that when requests from the Army in France came for instruments of new design, new sources of manufacture had to be sought out, and these organizations educated in the methods of precision optics. Such a procedure necessarily caused delay, but it was the only course of action left; wherever possible, part of the total contract was awarded to an experienced manufacturer, so that some production was assured.

The records show that the experienced manufacturers overcame the difficulties encountered, and had obtained in general a rate of output which was satisfactory at the time of the signing of the Armistice. The records

show also that many manufacturers who were relatively inexperienced in these lines undertook and successfully carried on the manufacture of other fire control instruments of French design, such as the telescopic sights for the 37 mm gun, the sight for the " tank " guns, the Schneider sight, the sitogoniometer, the collimator sights for the 75 mm gun, the anti-aircraft sights, as well as other material, such as plotting boards, aiming stakes, elevation and gunner's quadrants, azimuth instruments, periscopes ranging from 20 inches to 30 feet in length, field glasses, sextants, and gun sights.

There are a number of details which might be cited in connection with the general situation, but enough has been given to indicate that the problem of optical glass manufacture was met and solved, as a result chiefly of the co-operation between the Geophysical Laboratory and the manufacturers, and that we are now independent of Europe so far as optical glass is concerned; that the production of fire-control instruments was increased to such an extent that the requirements of the Army and Navy were well taken care of.

This has been done, of course, under high pressure and at considerable expense, but it has been a great pleasure to meet the problems as they came up day by day, and to see the difficulties disappear and the whole situation gradually clear. With but little optical glass in this country, with inadequate factory facilities, and few workmen available familiar with fire-control apparatus, this country was called upon to produce several hundred different types of instruments of exacting quality, and in large quantities. These included many new types of optical instruments which had been developed abroad during the war and were adopted by our Expeditionary forces; the more important of these are trench warfare material, anti-aircraft sights, and a host of sights for indirect fire-control. To do this required the building up of an adequate personnel within the Army and Navy, the control and co-ordination of the entire industry, the training of factory men, and the patriotic co-operation of the manufacturers. The fire-control program required, in short, all the available talent and resources of the country to carry it to a successful finish; the records show that despite innumerable difficulties which arose, the requisite rate of production was either attained or assured before the signing of the Armistice. It has been a source of inspiration to witness the high sense of patriotic duty and co-operation shown by the manufacturers, which made possible the remarkable expansion of the optical glass and instrument industry in the United States during

the period of the war. It is gratifying also to realize that in one more important industry this country has been rendered independent of foreign sources of supply.

ORDNANCE DEPARTMENT, U. S. A.
Washington, D. C.
December, 1918

THE FUTURE NEEDS FOR TESTING AND RESEARCH IN THE OPTICAL INDUSTRIES[1]

By P. G. NUTTING

This society was organized to advance the knowledge and practice of applied optics, and it is through testing and research that our knowledge of fundamental principles is increased and technical methods and products improved. Vast fields of research await investigation. This society may do much through stimulating research and co-operation between experts and between these and manufacturers.

INDUSTRIAL NEEDS

The relation of engineering and scientific research to industrial stability and progress is apparent in any of the larger manufacturing concerns. In a small manufacturing company, production and sales are close together, frequently under a single head. As the business grows an engineering department is added to look after the technical details of manufacture and to develop new designs and processes. With still further growth the engineering department is called upon for more and more scientific information. They must test raw materials and finished products to safeguard the interests of the company in their line of production. At the same time, more highly skilled specialists, chemists and assistant engineers are required to take care of more and more difficult details of design and testing. In the final stage a department of scientific research is added to aid the engineering research by investigating the more fundamental problems requiring too much time and too deep scientific knowledge to be handled by them. This in brief is the relation between testing and research in any industry; first, the engineering department to back up manufacture and sales, then a research department to aid the engineering department in special tests and general control of product and processes, with finally a scientific research laboratory to support the works research. Testing and research are closely related, although falling in different departments in a highly differentiated concern.

[1] A paper forming part of a symposium on the Future of Applied Optics at the third annual meeting of the Optical Society, Baltimore, Dec. 27, 1918.

In any industry based on accurate scientific knowledge, all progress depends primarily on testing and research. The optical industry is by no means unique in this respect, although the grade of testing and research associated with it is of the highest order. Raw materials must be constantly tested and checked and new designs made by difficult and rigorous methods. Check tests must be made all through the manufacturing process and the final product passed upon. Works troubles and changes constantly require investigation, while the more general and more difficult problems require extended prices of research.

EDUCATIONAL NEEDS

Aside from their direct and important bearing on manufacture, all kinds of testing and research are of the greatest educational value, and should form an essential part of any advanced courses of study in optical engineering. There is nothing to compare with a precision lens bench to give one a correct and lasting conception of the seven residual aberrations in corrected lenses. The illuminating engineer should be as familiar with the photometer as the physician is with the clinical thermometer. He should have had extended practice with all kinds of testing, giving him complete familiarity with light sources, diffusing media and light distribution. He should also possess a familiarity with the response of the human retina to light, which can only be gained through accurate laboratory tests and measurements and the plotting of innumerable curves. The varied phenomena of crystal optics can never be clear to the mind of one who has not made innumerable laboratory determinations on crystals. Similarly a command of the varied fields of colorimetry, interferometry, refractometry and radiometry can be gained only through accurate work, done with a variety of instruments under a variety of conditions. There is no short cut to becoming an expert in any branch of applied optics; the best means to that end is beyond question through laborious research.

Up to the present time our experts in applied optics have been almost entirely self-made, that is, starting with a good foundation in pure optics, they have, by individual work in designing, testing and research, acquired command of their respective specialities. We believe that the time is now ripe for the formation of an Institute of Applied Optics in which research will be supplemented by instruction by our leading experts. A rough estimate of the annual demand in this country for trained experts in each line is as follows: In lens and instrument design, testing and research, 20;

refractometry of glass, gas, milk and butter fat, 10; colorimetry and spectrophotometry, 10; optometry and opthalmology, 800; illuminating engineering and photometry, 50; pyrometry, radiometry and spectroradiometry, 50; polarimetry and saccharimetry, 12; birefractometry and petrography, 6; testing research and control of photographic goods, 30. The training of such a body of experts would tax the facilities of a fairly large college of applied optics.

OUTSTANDING PROBLEMS

A summary of some of the more important research problems awaiting solution in applied optics was given by the author at the first meeting of the first section of this society to be formed, in Rochester, January 4, 1916. This was published in *Science*, January 28, 1916. In this discussion were reviewed problems of pure optics, lens and instrument design and construction, the photographic reaction, visual sensitometry, colorimetry, photometry and polariscopic analysis. Sufficient research work was there outlined to occupy the attention of a great many investigators for a number of years.

The very ground work of all applied optics is of course *pure optics*. Little progress can be made without a thorough knowledge of the laws of the refraction, reflection, absorption and emission of light, nor of diffraction, interference, scatter or polarization. Most of these laws are well known and familiar, but there are conspicuous exceptions of vital importance in applied optics. The laws of radiation applicable to a perfect radiator are fairly complete, but very little is known of the corresponding laws applicable to the practical case of heated bodies or to gases conducting an electric current. While the laws of reflection and refraction are commonly considered well known, as a matter of fact, we know almost nothing of the laws applicable to a layer whose thickness is comparable with the length of a light wave. In this case, practice has not waited for theory, for lens surfaces are said to have been prepared giving greatly decreased loss of light by reflection. Another and conspicuous gap in our knowledge of pure optics relates to heterogeneous media. Light is scattered by small particles and absorbed by still smaller ones, but very little attention has been given to the laws governing the scatter and diffusion of light so important in illuminating engineering.

In the field of *lens calculation*, though great results have been achieved, our methods and mathematical tools are those of fifty years ago. We still calculate lenses largely by the cut and try method of triangulating a bundle of rays through the lens and finding whether they meet in the image plane.

It is possible that no other method of calculating lenses will ever prove of practical value, yet a number of our ablest mathematical physicists have attempted to apply the best modern mathematical methods to lens design. Their results have been interesting, but of practical value only in limited fields. The consensus of opinion today appears to be that if the seven lens aberrations could but be expressed in a suitable language, they would assume comparatively simple forms in equation readily soluble. It is quite certain, however, that such simplicity is impossible in any of the mathematical systems yet tried, and that the desired result will only be possible in some system not yet invented.

Our next greatest needs in lens design are generalizations and publicity. In every complete set of calculations for a given lens, conclusions are arrived at relating changes in radii, thickness, separation and glass indices to variations in the degree of correction, in other words, a set of differentials is obtained, by the laborious methods of ray triangulation. Yet these very valuable results are regularly allowed to go either to the waste basket or to the locked notebook. The renowned Abbe set a worthy example of world-wide usefulness by having prepared and published tables for the selection of companion glasses for telescope objectives, thereby saving others hundreds of hours of labor. If we followed his worthy example, we should publish sets of differentials applicable to each of the important lens types as soon as obtained and thus obviate a tremendous waste of time in duplicating results. In particular, we need publication and public discussion of such material as general rules for the spectral correction of objectives for photographic and visual purposes, general rules for reducing distortion, for locating and displacing Gauss points, limits of tolerance in definite and resolving power, description of the best methods of testing objectives and the like.

In the design of *optical instruments* a similar lack of co-ordination and generalization is apparent. The instrument-using public has been too often ignorant and always tolerant of defective design. The average user accepts without question, as he is without recourse, instruments hastily conceived and imperfectly worked out in design. Our largest makers employ specialists in the design of each class of instruments. Lesser makers of the less used instruments, such as spectroscopes, photometers and radiometers, seldom have the benefit of the crystallized general opinion of those users of his instruments who know what the performance of a first-class instrument should be. We trust that every class of both user and designer of optical instruments will derive benefits from this organization.

No optical instrument can be of any service without either an eye or a photographic surface as an adjunct. The properties of these should, therefore, be well known to the designer of lenses and instruments as well as to those more directly interested in them. The material of these three chief branches of applied optics (lens design, vision and photography) is, however, widely scattered and few who are well posted in one branch are even well informed in the other two.

The fundamental problem of *the photographic surface* is the rendering of the light impressed upon it. The quantitative relations between exposure, development and density of image were obtained by Hurter and Driffield twenty years ago. Since that time, much has been found out concerning the nature of the latent image and of development and the conditions which govern speed and density gradient. The greater part of the preliminary work in photographic research may be regarded as complete.

Investigation in photography is now centered upon the more recondite problems and a clearing up of the nature of the photographic processes. We are not yet able to express photographic density as a function of energy, wave-length and time. The relation between plate speed and wave-length is known for but few emulsions. Speed varies with both absolute intensity of radiation and the rate at which it is applied according to laws not yet understood. The maximum density gradient obtainable varies with exposure, wave-length, emulsion and development in ways now being investigated. A knowledge of the resolving powers of the photographic surface, of the eye and of the lens or the optical instrument, of which it is a part, is of the utmost importance to workers in almost every line of applied optics.

The photographic emulsion is optically a translucent medium of high scattering power. The penetration of light into such media varies a great deal with the wave length of the light, with size of grain and with distance and direction in the medium. Hence, a knowledge of the optical laws governing scattered light is of the utmost importance in photographic research, and of such laws but very little is known.

The photographic reactions to light bear a close resemblance in many respects to the reactions of the retina, and from the optical properties of the retina much information may be drawn that throws light on the photographic effects and vice versa. Hence, the investigation of the retinal and photographic reactions may very properly be carried on side by side, and results obtained in either field applied in the other.

Intimately related to all branches of applied optics are the visual properties of *the human eye*. Broadly stated, what is known of the eye as an optical instrument constitutes but a rough working knowledge of it. The curvatures, thicknesses and refractive indices of the various eye media in an average normal eye are fairly well known, as well as the location of the nodal points and center of rotation. Three of the third order aberrations are important in vision, namely the spherical aberration, the chromatic variation of the spherical aberration and the axial chromatic aberration. Of these only the last has been studied and measured, and that only recently. One remarkable result of these measurements is the discovery that many eyes possess a type of axial chromatic correction previously unknown in lens optics, and which probably could not easily be duplicated in a glass lens. It is hoped that methods of measuring the two other aberrations will shortly be devised and applied.

The nature of the reactions of *the retina* to light have been extensively studied during the last twenty years. But the problems requiring investigation are many and difficult, and scarcely more than preliminary results have yet been obtained. The visual impression requires time to originate, and grows at a rate varying with both the intensity and wave-length of the light producing it, as well as with the previous treatment of the retina. It is no simple matter to isolate and measure these various reactions not to correctly interpret the results obtained.

Most studied and best known is the relative brightness of the same amount of radiation of various wave-lengths, the so-called "visibility" of radiation. This is a measure of the relative sensibility of the retina to light of different wave-lengths but of equal energy. This relation is known for a great number of subjects to a quite satisfactory precision. It establishes the ratio of the light unit to the energy unit, hence, is of fundamental importance in illuminating engineering. Strictly speaking, we can neither define nor measure light without it.

When it comes to measuring the light sensation caused by a given light impression, an apparently insurmountable difficulty is encountered, for a sensation can not be directly measured. The sensation is, however, the integral of the sensibility, and the sensibility is proportional to the reciprocal of the just noticeable difference in intensity and this may readily be measured. The necessary data are being accumulated, and before long we shall be able able to formulate the general laws of the visual reaction to

light intensity in the case of white light. Similar data relating intensity sensibility to color, intensity and time would be of great usefulness.

On entering a dark room, we become able to distinguish objects after a shorter or longer interval of time depending upon various conditions not yet worked out. Rate of adaptation curves must be determined for all initial conditions of adaptation, not only for white light, but more particularly for the reds, yellows and greens used in the safe lights of dark rooms.

Very little is yet known of the relation between visual acuity and the brightness of the object viewed. The ability to distinguish fine details is known to fall off rapidly with decreasing illumination, but we have not the data for the formulation of any laws.

Illuminating engineers require a mass of such data on the properties of the retina, for the eye is the sole means of judging whether lighting is good or bad, and the conditions for best seeing have been only very roughly worked out thus far. We require to know what illumination levels and what contrasts are best, and what are the effects of excessive contrasts and oblique glare in depressing the sensibility of the retina.

The precise measurement of *color* is an almost unworked but important field of applied optics. The preliminary part of the work only has been done. The underlying theory has been roughed out, methods have been devised and precision colorimeters designed. But our fundamental color scales have been only partly worked out, and the various laws of color combination are practically unknown. The work urgently requiring attention in this field amounts to quite a number of man-years.

Within the necessary limits of this discussion only the more urgent problems in the more important fields of applied optics could be reviewed. The special problems of refractometry, radiometry, interferometry, spectrophotometry, polarimetric analysis and other fields of applied optics belong also to pure optics and are more or less familiar to all advanced students of optics.

The research work in applied optics here mentioned is many times more than can be undertaken by the combined efforts of all our teaching institutions and our national and industrial research and testing laboratories for many years to come. No more interesting or enticing problems can be found in any field. It is to be hoped that this society may exert a strong influence in increasing the quantity and enhancing the quality of the research work done.

RESEARCH ON WAR PROBLEMS

The demands of warfare in optical design and manufacturing were many times those of peace, and extended into fields to which very little attention had previously been given. Notable advances have been made in the theory of lens design, in production of optical glass, in the design of special instruments for observation, both visual and photographic, as well as in colorimetry, lighting and in the design of miscellaneous optical instruments. A great deal of fundamental research has been carried out and it would be well for this society to salvage as much as possible of the information and data specially developed, and to urge the completion and recording of all unfinished work which may be of permanent value.

INFLUENCE OF THE SOCIETY ON PROGRESS

This society may do much to further industrial progress in this country and secure to it the industrial independence for which it is so well fitted. Let us review briefly those lines of activity concerned with testing and research which appear to be within its scope and promising of practical and lasting results. By a judicious use of its influence through its officers and standing committees this society may accomplish much towards (1) increasing the supply of trained optical experts in this country, (2) improving the methods of testing and research, and (3) increasing our knowledge of the fundamental principles in each branch of applied optics. The specific objectives of such activities of the society should be in each case the increased production of optical goods in a wider variety and of continually higher grade.

Three lines of activity are open to the society to secure these desired results, namely (a) through higher education in applied optics in our leading universities, (b) furthering the development of greatly increased testing and research by the government at Washington, and (c) increasing and extending industrial research. The value of such research and training has been indicated at the opening of this article. Practical results along these lines are to be secured through active technical and educational committees of this society.

A committee on Industrial Research, for example, might collect information as to the special needs and problems of different manufacturing plants, and advise them as to the best means of overcoming their troubles and improving their products. Such a committee might well improve the cooperation between different industrial plants and secure for each the services

of various experts who may be available for such work. In extreme cases such a committee might even undertake the investigation of certain problems, or in other ways secure the information required.

A committee on Education and Training is urgently required to take up with two or three of our leading universities the matter of offering advanced courses, leading perhaps to the degree of Optical Engineer, so located as to draw students from different parts of the country. With active support there is no reason why Rochester should not become the optical center of this country, if not of the world. Plans were drawn up more than two years ago for the courses to be offered in a high grade graduate school of Applied Optics with an estimate of the probable annual demand for experts in each line per year in this country, and estimates of the staffs and time required to provide the desired instruction. The chief requirement in this line is to secure harmony of purpose and concentrate effort along certain well-defined lines.

A committee on Nomenclature and Standards could accomplish a great deal in harmonizing matters of notation, standard tests, standard threads for objectives, outlining the standards of performance for various types of standard optical goods and in bringing about uniformity of nomenclature. Fixing high standards in this way would exert a profound influence on the manufacturing industries toward raising the grade of their products and might do much toward harmonizing international standards.

Other committees of probable usefulness might be appointed such as a committee on Progress to review the chief optical advances of the world in annual reports; a committee to take up the interrelations of this society with other societies covering neighboring fields, such as illuminating engineering, physics and astronomy; a committee to take up the matter of national research and testing in applied optics in some laboratory, to act as advanced head for all optical research in the country; a committee on Research to outline the most urgent problems of applied optics and to exert its influence in having research on such problems initiated in the various laboratories available.

Finally the influence of this society through its Journal and other factors in publicity can hardly be over estimated in its stimulus to publication and research and in securing harmony in progress in any line. A well-edited journal filled with valuable material and open to wide discussion cannot fail to be of the utmost usefulness in promoting industrial progress.

We should give the Journal our hearty support in every way. It has an open field and has made a good beginning, and there is every prospect of its successful continuance. Through it the society may go further and exert its influence toward the preparation of a series of text and reference books in the various fields of applied optics. This country is already well represented in this line of activity, but there are a number of fields as yet not cared for, and in every line there is need for reference books written by experts which shall summarize all the newer and more valuable results of testing and research.

WESTINGHOUSE RESEARCH LABORATORY
East Pittsburgh, Pa.
December, 1918

PROTECTION OF SILVERED SURFACES

By F. KOLLMORGEN

At the commencement of the European War the importation of optical glass stopped completely, and at that time no glass suitable for optical instruments was being manufactured in this country. While it appeared probable that before long the glass industry of the United States would be in a position to turn out the ordinary kinds of optical glass, such as Crown and Flint, it was doubtful how long it would take before the considerable difficulties attending the manufacture of the more modern varieties of glass such as Borosilicate Crown and Baryum Crown would be solved. Being engaged in the manufacture of periscopes for submarines, in which eyepiece reflectors of considerable size are used, the writer foresaw serious trouble unless some reflector could be developed which could take the place of the Borosilicate prisms so far employed for that purpose. A plain glass mirror silvered at the surface, of course, presented the easiest solution provided the surface could be protected efficiently against atmospheric influences. While looking up the subject of the possibility of such protection which, of course, must not in any way interfere with the optical efficiency of the mirror, it was found that as late as 1894, Mr. Izarn published in the *Comptes Rendus* a protective coating of bichromated gelatine which he had applied on a 33 centimeter telescope reflector at the Toulouse Observatory. This reflector withstood the influence of sulphuretted hydrogen for 24 hours without change. In 1909 Mr. A. Pérot described, also in the *Comptes Rendus*, a protective coating consisting of celluloid dissolved in amylacetate.

Mr. Louis Bell in the *Electrical World*, 1913, mentions the employment of a commercial lacquer sold under the name of Lastina Lacquer for the same purpose with very good results. It appears that a two-foot parabolic reflector used at the Harvard Observatory, protected in this manner, lost only 4% of its original light transmission through the lacquering, and after three months service still retained 70% of its original light transmission.

Both Mr. Pérot's and Mr. Bell's papers, however, state that the lacquer must be used in a very thin layer and will show interference colors. The first experiments made by the writer produced an efficient protection, but it was found that the interference colors showed plainly when the eyepiece was used on a periscope and this phenomenon had to be overcome. When the coating of lacquer was sufficiently thick to show no interference colors the lacquer dried sometimes in waves and streaks, and sometimes with a crinkly surface seriously damaging the definition of the mirror, and it occurred to the writer that this appearance might be avoided by centrifuging the mirror during the drying so that the surface would be kept under an even tension until dry. An experiment along these lines proved very satisfactory and mirrors protected in this manner have been used since in a large number of periscopes with very good results. Even after a year's use the mirrors have shown no appreciable decrease in efficiency and no appearance of tarnishing whatever. The reflecting power of these mirrors is greater than that of a prism for in some of our periscopes we have employed a mirror at the top for the high power and a prism for the low power and the increase in light transmission from low to high power has been quite noticeable. Owing to the rush of war work it has, unfortunately, been impossible to make exact measurements of the light transmission.

The protection given by the coating of lacquer is, however, a very slight one against mechanical damage, as the lacquer is very soft and will scratch at the slightest touch. If dust should settle on the mirror it must be removed by means of a very fine camel's hair brush; a soft piece of chamois leather may be employed if care is taken that it is absolutely free from grit or dust. Attempts to harden the lacquer by baking have not proven successful. Various other lacquers and varnishes that were tried did not give as good optical results as the Lastina lacquer. Mr. Bell's paper suggests that lacquer should be thinned down in the proportion of one part lacquer to six parts commercial thinner. We use one part lacquer and two parts thinner with our method.

A ONE-TERM PURE EXPONENTIAL FORMULA FOR THE SPECTRAL DISTRIBUTION OF RADIANT ENERGY FROM A COMPLETE RADIATOR*

By Irwin G. Priest

The radiant energy from a complete radiator ("black body") may be well represented as a function of temperature and wave-length by the following empiric formula which does not appear to have been noticed heretofore:

(1)[1] $$E_\lambda = D_1 T^5 e^{-D_2 [A^{-\frac{1}{4}} - (\lambda T)^{-\frac{1}{4}}]^3}$$

where

$E_\lambda \equiv$ energy of wave-length λ in the same sense as in the Wien and Planck equations.

D_1 and D_2 are constants.

$T \equiv$ absolute temperature in degrees Kelvin.

$A \equiv$ Wien displacement constant in micron degrees.

$\lambda \equiv$ wave-length in microns.

From equation 1, we have, for relative energy at any constant temperature:

(2) $$E_{\lambda r} \equiv \frac{E_\lambda}{E_m} e^{-D_2 [A^{-\frac{1}{4}} - (\lambda T)^{-\frac{1}{4}}]^3}$$

where

$E_m \equiv$ maximum energy.

The following are noteworthy properties of these equations:

1. Actual numerical computations for $D_2 = 4481$ and $A = 2890$, by equation 2 give results in approximate agreement with the Planck equation for $C_2 = 14350$, and $A = 2890$. See accompanying table.

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* Abstract of a communication to the Optical Society of America, Baltimore, December 27, 1918. The author presents this communication merely as a preliminary statement of an observed empiric relation, which may possibly prove to have some theoretical significance, without, at present, making any representation as to its significance or importance. He is giving the formula further consideration and if it should prove to be of further interest, it will be discussed in more detail in a subsequent paper. This abstract gives only the essential statement of the equation and its characteristic properties in the hope that it may be suggestive to others.

[1] The symbols are somewhat different from those used at the meeting, but the essential relation intended to be represented is the same, and more clearly expressed. This equation was first obtained by graphic transformations of the Planck equation.

2. Equation 2 represents Coblentz' experimental data at 1596.5°K[2] about as well as the Planck equation does. (Values of all constants as under 1, just above. *See also discussion at end of abstract.*)

3. These equations include the general as well as the special case of the Wien displacement law, for the following relation may be derived from equation (2) for constant relative energy ($E_{\lambda r}$) at any temperature:

$$(3) \qquad \bar{\lambda}T = \left(\frac{1}{A^{-\frac{1}{4}} \pm \sqrt{\frac{\log_e E_{\lambda r}}{-D_2}}} \right)^3$$

which conforms to the general case of Wien's law, viz: λT is same function of $E_{\lambda r}$ for any value of temperature. The special case of Wien's law, $\lambda_m T = A$, may be inferred from inspection of equation (1) or (2) for condition of maximum E_λ or $E_{\lambda r}$.

4. Equation (1) includes the law that:

The maximum energy is proportional to the fifth power of the absolute temperature, as may be seen by inspection of the equation for the condition

$$\lambda = \lambda_m = \frac{A}{T}$$

5. Equation (1) has precisely the form of the well-known equation of the "probability curve"[3] which suggests that the proposed equation may have some significance, other than a mere empiric relation. If $E_{\lambda r}$ (equation 2) be plotted as ordinate against $\sqrt[3]{\frac{1}{\lambda}}$ or $\sqrt[3]{\frac{300}{\lambda}}$ (cube root of frequency) as abcissa, the result is a curve strictly symmetrical about the maximum ordinate.

If the general validity of the equation as representative of experimental data be admitted, this suggests a very convenient means of determining the wave-length of maximum energy from an isothermal curve. Graphically, the intersection of the axis of symmetry with the abcissa scale gives $\sqrt[3]{\frac{1}{\lambda_m}}$

[2] B. S. Sci. Paper 284, Fig. 2, p. 476. Values have been scaled from the large original of figure, kindly loaned by Dr. Coblentz for this purpose.

[3] Merriman, Method of Least Squares, p. 25, 8th Ed. Revised, 1910.

λT	Values of $\frac{E_\lambda}{E_m}$ as a Function of λT — Computed by Formulas — For A = 2890: Wien C_2=14450	Planck C_2=14350	Proposed Equation* Priest, Dec.'38	For A=2940: Planck C_2=14597	Proposed Equation* Priest, Dec.'38	Exp. Data× Coblentz B.S. Sci. Pap. 284, Fig 2 T=1596.3 K	Residuals: Planck for A=2890 minus Exp. Data	Proposed Equation for A=2890 minus Exp. Data	Planck for A=2940 minus Exp. Data	Proposed Equation for A=2940 minus Exp. Data
Column No.	(I)	(II)	(III)	(IV)	(V)	(VI)	(II)-(VI)	(III)-(VI)	(IV)-(VI)	(V)-(VI)
500	0.27X10^{-6}	0.32X10^{-6}	0.87X10^{-6}	Note →						
800	.13X10^{-3}	.14X10^{-3}	.18X10^{-3}		0.72X10^{-4}					
942		.94X10^{-2}	.11X10^{-1}		1.6X10^{-2}					
1000	.16X10^{-1}	.17X10^{-1}	.19X10^{-1}	0.78X10^{-2}	0.96X10^{-2}	0.15X10^{-1}	−0.006	−0.004	−0.007	−0.005
1102		.39X10^{-1}	.42X10^{-1}	.34X10^{-1}	.38X10^{-1}	.35X10^{-1}	+0.004	+0.007	−0.001	+0.003
1215		.80X10^{-1}	.82X10^{-1}	.71X10^{-1}	.77X10^{-1}	.58X10^{-1}	+0.022	+0.024	+0.013	+0.019
1325		.1391	.1420	.1254	.1320	.110	+0.029	+0.032	+0.016	+0.023
1485		.2525	.2558	.2334	.2406	.233	+0.019	+0.023	+0.000	+0.008
1500	.2582	.2646	.2678							
1676		.4151	.4166	.3904	.3973	.395	+0.020	+0.022	−0.005	+0.002
1788		.5135	.5150	.4877	.4929	.495	+0.019	+0.020	−0.007	−0.002
1900		.6079	.6096	.5827	.5863	.581	+0.027	+0.029	+0.002	+0.005
2000	.6810	.6871	.6859							
2044		.7183	.7175	.6859	.6963	.700	+0.018	+0.018	−0.004	−0.004
2155		.7924	.7926	.7700	.7722	.797	−0.005	−0.004	−0.027	−0.025
2427		.9238	.9240	.9111	.9094	.929	−0.005	−0.005	−0.018	−0.020
$\lambda<\lambda_m$										
Max → 2714		.9803	.9800	.9859	.9848	.994	−0.004	−0.004	−0.008	−0.009
$\lambda>\lambda_m$ 2898		.9972	.9975	1.000	.9995	.998	−0.001	−0.000	+0.002	+0.002
3000	.9964	.9960	.9966							
3257		.9665	.9675	0.9769	.9753	.963	+0.003	+0.005	+0.014	+0.012
3512		.9180	.9167	.9322	.9296	.940	−0.022	−0.023	−0.008	−0.010
3624		.8916	.8900	.9078	.9053	.911	−0.019	−0.021	−0.003	−0.006
3840		.8368	.8332	.8553	.8509	.864	−0.027	−0.031	−0.009	−0.013
4000	.7887	.7987	.7933							
4071		.7788	.7730	.7976	.7929	.771	+0.008	+0.002	+0.027	+0.022
5000	.5323	.5515			.5635					
5843		.3950	.3808	.4117	.3899	.397	−0.002	−0.016	+0.015	+0.003
6000	.3465	.3712	.3566							
6003		.3712	.3570	.3868	.3751	.374	−0.003	−0.017	+0.013	+0.001
6434		.3133	.2978	.3274	.3146	.313	+0.000	−0.015	+0.014	+0.002
7088		.2439	.2288	.2558	.2437	.244	−0.000	−0.015	+0.012	−0.000
7408		.2165	.2021	.2275	.2155	.218	−0.002	−0.016	+0.010	−0.002
7695		.1949	.1807	.2047	.1926	.197	−0.002	−0.016	+0.008	−0.004
7983		.1756	.1615	.1847	.1731	.179	−0.003	−0.017	+0.006	−0.006
8000	.1501	.1746	.1607							
8238		.1608	.1466	.1690	.1574	.160	+0.001	−0.013	+0.009	−0.003
8493		.1469	.1340	.1546	.1437	.147	−0.000	−0.013	+0.008	−0.003
8765		.1340	.1212	.1412	.1305	.132	+0.002	−0.011	+0.009	−0.002
9930		.9270X10^{-1}	.8171X10^{-1}	.9770X10^{-1}	.8619X10^{-1}	.8617X10^{-1}	+0.006	−0.005	+0.011	+0.002
10000	.7 1X10^{-1}	.9000X10^{-1}	.8001X10^{-1}		← Note Agreement →					
20000	.45X10^{-2}	.86X10^{-2}	.69X10^{-2}	Note Agreement of Cols. II, III, V. cf. Low values in λ.	.771X10^{-2}		Note Systematic High Values for λ < λ$_m$ ↓			Note Small Residuals and Distribution of Signs cf (III)-(VI) ↓
30000	.76X10^{-3}	.19X10^{-2}	.15X10^{-2}		.631X10^{-3}					
40000	.20X10^{-3}	.65X10^{-3}	.54X10^{-3}							
50000	.72X10^{-4}	.28X10^{-3}	.25X10^{-3}		.151X10^{-3}					
60000	.30X10^{-4}	.14X10^{-3}	.13X10^{-3}		.60X10^{-4}					
70000	.15X10^{-4}	.75X10^{-4}	.74X10^{-4}							
80000	.76X10^{-5}	.45X10^{-4}	.51X10^{-4}		.29X10^{-4}					
90000	.43X10^{-5}	.29X10^{-4}	.35X10^{-4}							
100000	.26X10^{-5}	.19X10^{-4}	.25X10^{-4}							

Means			Residuals (II)-(VI)	(III)-(VI)	(IV)-(VI)	(V)-(VI)
for λ < λ$_m$	Arith.		+0.015	+0.016	+0.009	+0.010
	Algeb.		+0.012	+0.013	−0.004	−0.0004
for λ > λ$_m$	Arith.		+0.006	+0.014	+0.011	+0.005
	Algeb.		−0.004	−0.013	+0.008	−0.0003
for all values of λ	Arith.		+0.010	+0.015	+0.010	+0.0075
	Algeb.		+0.003	−0.002	+0.003	−0.0003

Notes to Column Headings III, V, VI.

*Proposed Equation $\frac{E_\lambda}{E_m} = e^{-14381\left[A^{\frac{1}{2}}-(\lambda T)^{\frac{1}{2}}\right]^2}$

×Omitting points affected by atmospheric absorption.

from which λ_m may be obtained directly, or by algebraic solution:

$$\lambda_m = \frac{8}{\left(\sqrt[3]{\frac{1}{\lambda_1}} + \sqrt[3]{\frac{1}{\lambda_2}}\right)^3} \tag{4}$$

where λ_1 and λ_2 are the wave-lengths for equal relative energy.

DISCUSSION

In anticipation of a question as to the integration of equation 1, the author stated that he had not yet succeeded in obtaining a rigorous integration leading to the Stefan Law (total energy proportional to fourth power of absolute temperature); although this law would be indicated by graphic integration. Dr. Nutting stated that if graphic integration led to the Stefan Law, the definite integral when obtained must necessarily conform closely to this law. Mr. Foote then pointed out that exact and not merely approximate integration was required to derive the Stefan Law.[4]

Dr. Ives inquired if the law of symmetry noted under 5, above, had ever been previously noticed, and the author replied that it had not so far as he was aware.

Subsequent to the meeting, Dr. Coblentz pointed out that any equation to be of value should conform to his data[5] at certain particular points ($E_{\lambda r}$ = about 0.1 to 0.3 for $\lambda > \lambda_m$) better than the proposed equation does with the constants given under 2 above. This led the author to further consideration of this question resulting in the following conclusions:

1. The value, A = 2890 as given by Coblentz[6], has been obtained from his data *by solution of the Planck equation assuming that it represents the data*, which it does to a close approximation, in fact to a closer approximation than any other equation *heretofore* proposed; but it does not perfectly represent the data.

2. Assuming that the present proposed equation (2) represents the data and solving it for A as under 5 above, using the same data, we obtain A = about 2920 – 2940 (the variation depending on how the points are weighted).

[4] Since the meeting, the author has obtained (December 31, 1918) what appears to him to be a rigorous integration showing that the Stefan law may be derived mathematically from equation (1). In this connection he desires to acknowledge with thanks the advice and suggestions of his associate Mr. E. P. T. Tyndall, with whom he has discussed the problem of this integration.

[5] B. S. Sci. Paper 284, Fig. 2, T = 1596.5 K.

[6] B. S. Sci. Paper 284.

3. *With this value of A, the proposed equation represents the data for the whole isothermal curve better than the Planck equation with either value of A.* See accompanying table, noting particularly the table of residuals.

The possibility of this happening is due to the fact that when A is so chosen in the Plack formula as to make the computed curve agree best with the data at about $E_{\lambda T} = 0.2$ for $\lambda > \lambda_m$ the curve so obtained does not perfectly represent the data for $\lambda < \lambda_m$ nor indeed for $E_{\lambda T}$ = about 0.90 to 0.95 for $\lambda > \lambda_m$.

Since the meeting, Dr. Nutting has written the author inquiring concerning the proposed formula in its application to extremes of wave-length. In reply to this, reference is made to the accompanying table.

It will be noticed that for large as well as small values of λ T, the new formula approximates the Planck formula which has been accepted as truly representing the data. The largest differences which occur in the region $E_{\lambda T} = 0.02$ to 0.3 for $\lambda > \lambda_m$ are in the sense that the proposed formula agrees with the experimental data[7] on both sides of the maximum better than the Planck formula, *provided that the constant A is independently determined by each formula.* (See also discussion of Dr. Coblentz' remarks just above.)

It appears probable that, if this formula should be adopted as a working hypothesis and the empiric constants D_2 and A be determined by it, it would be found to represent the data even better than the Planck formula; but this may be considered an open question, the decision of which would require a great amount of careful experimental work as well as elaborate computations and comparisons of results.

NATIONAL BUREAU OF STANDARDS
January 27, 1919

P. S.—March 25, 1919. See also later abstract, "A New Formula for the Spectral Distribution of Energy from a Complete Radiator", Irwin G. Priest, New York Meeting of American Physical Society, March 1, 1919, to be published in *The Physical Review.* I. G. P.

[7] B. S. Sci. Paper 284, Fig. 2, T = 1596.5 K.

PHOTO-ELECTRIC SPECTROPHOTOMETRY BY THE NULL METHOD

By K. S. GIBSON

In connection with the color standardization work of the National Bureau of Standards, [1] it is desired to have as many as possible independent methods of making spectrophotometric determinations, especially in the visible part of the spectrum; for it is generally admitted that the fundamental basis of color specification is spectrophotometry. To supplement the other methods at present in use at the Bureau, and especially to overcome the well-known uncertainty of measurements by these other methods in the blue and violet, the author in 1917 was given the problem of developing a method for accurate and convenient photoelectric spectrophotometry suitable for routine determinations, especially the measurement of spectral transmission.

The sensitive *potassium hydride* photo-electric cells now on the market, when used with an incandescent lamp and a glass dispersing prism, give a maximum response usually near 460 millimicrons. A null method was decided upon for reasons mentioned below, an electrometer serving merely as an indicator of equality between two photo-electric currents. The making and assembling of apparatus was completed in April, 1918; and since that time has been in constant, almost daily use, being very satisfactory as to ease of keeping in working condition, speed of operation, and accuracy of measurement.

The apparatus and electrical connections are outlined in the diagram, which with its accompanying key is practically self-explanatory.

[1] I. G. Priest, The Work of the National Bureau of Standards on the Establishment of Color Standards and Methods of Color Specifications, Trans. I. E. S., XIII, 38, 1918.

PHOTO-ELECTRIC SPECTROPHOTOMETRY BY THE NULL METHOD

K. S. GIBSON

KEY TO DIAGRAM

Apparatus drawn to scale shown in diagram, except for batteries and a few other minor details.

FFFF Slate slab supported by two concrete pillars resting on basement floor.

IIII Cast-iron base 3.5 cm thick resting upon slate slab.

JJJJ Aluminum box 50 cm high, divided into 3 compartments by partitions N, fitting into brass channels on iron base. Has aluminum cover fitting into brass channels at top of box.

E Dolezalek quadrant electrometer, resting on iron base, with aluminum disk E′ suspended by platinized quartz fiber.

P_1P_2 Kunz potassium hydride photoelectric cells, supported by tripods resting on iron base.

AAA Pieces of polished amber with brass rods through centers.

G Ground wire connections to water pipe. Cast-iron base, aluminum box, electrometer case and one pair of quadrants permanently grounded.

U U-tube filled with mercury into which dips an amalgamated, pointed copper wire. Used for make-and-break ground connection for second pair of electrometer quadrants, controlled from X, X′ or X″.

WW_1W_2 Windows.

H Hilger constant-deviation spectrometer, resting on slate slab, with glass prism and accurately adjustable bilateral slits S_2 and S_3.

T Track of iron photometer bench resting on ground floor.

L_3 Mazda C moving picture lamp rated at 600 watts (30 volts 20 amperes), filament in one plane about 1 cm square, completely enclosed except for concealed ventilating openings and openings 3 cm in diameter in front and back of filament. L_3 is carried by a three-wheeled car moving along photometer track, and carrying a marker directly beneath filament by which its distance from slit S_2 may be read on scale shown in diagram.

Z Black felt screens supported on T, enabling measurements to be made with other lights in the room.

Y Rotating sector and motor Y′ supported on T, used to test inverse square law for L_3 and to increase range of measurements.

C Sliding carrier, supported on T, containing specimen B, whose transmission is to be measured. Carrier slides back and forth from C to C′.

Q Container for selective ray filters.

L_1 Mazda C automobile headlight lamp rated at 15–20 watts (7 volts 2–3 amperes), enclosure similar to that for L_3, supported by iron base. L_1 and L_2 are run in parallel with suitable adjustable resistances on a 60-volt storage battery.

S_1 Accurately adjustable bilateral slit, supported on iron base, identical with S_2 and S_3.

Q′ White opal glass screen.

V Battery of Eveready cells usually about + 150 volts by which electrometer disk may be charged through conducting suspension.

V_1V_2 Battery of Eveready cells, usually about 40 and 80 volts respectively, of such value that the dark currents through P_1 and P_2 are equal.

R Adjustable high resistance.

KK_1K_2 Knife switches.

L 25-watt vacuum tungsten lamp. Light from filament is reflected and focused by small mirror on electrometer disk to give image on 50 cm ground glass scale at D.

X Approximate position of observer when scale is at D.

X′D′ X″D″ Other positions of observer and ground glass scale under conditions explained in paper. In these cases, light from L is reflected to D′ or D″ by a mirror M′ or M″.

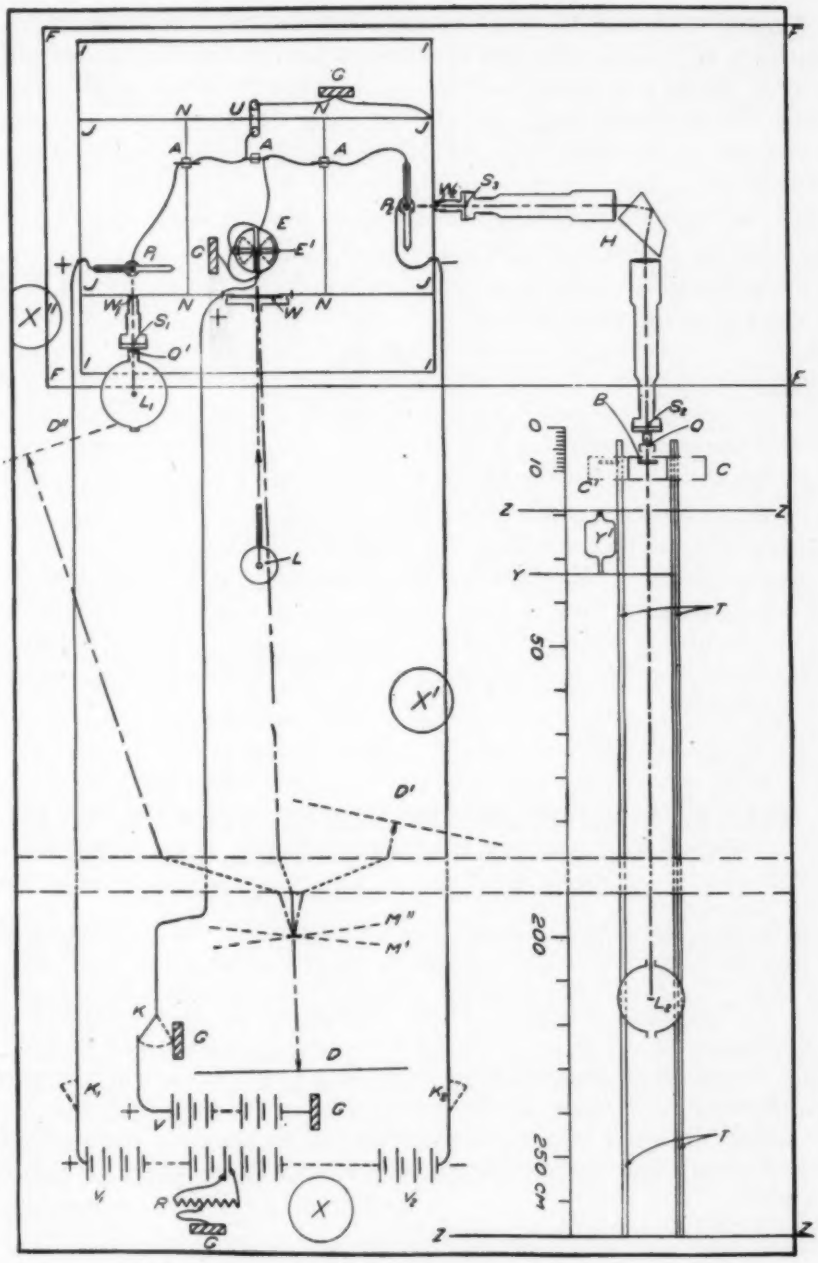

Diagram of Apparatus
Photo-electric Spectrophotometry by the Null Method.

Measurements of spectral transmission are made by observing the distances of L_2 from S_2 necessary to obtain a balance (of the electrometer, as indicated by the zero motion of the spot of light on the scale D) with and without the specimen B in position, all other factors such as slit-widths, currents, etc., being kept constant. The ratio of the squares of these two distances respectively is the transmission of B. By this use of the null method, all errors are eliminated, as well as the necessity of any kind of calibration, in connection with the relation between photo-electric current and incident radiant power, in connection with the dark currents through the photo-electric cells, and in connection with electrometer deflection methods. The accuracy has been tested in various ways, chief of which are the measurements of rotating sectors of known transmission, and comparisons with values obtained by other methods. It is considered that the uncertainties of measurements from 410 to 550 millimicrons inclusive are not greater than 0.01 for any values of transmissions between 0.00 and 1.00, and are very definitely much less than that for values from 0.00 to 0.10. Measurements can be made from 380 to 650 millimicrons.

The apparatus is also adapted to the measurement of spectral diffuse reflection relative to that of a standard such as magnesium carbonate, to the measurement of the relative distribution of radiant power of two sources, to the measurement of fluorescence, and to other kinds of measurements of less importance.

NATIONAL BUREAU OF STANDARDS
Washington, D. C.
December 13, 1918

THE ABSORPTION OF ULTRA-VIOLET AND INFRA-RED RADIATIONS BY GLASSES

By ALPHEUS W. SMITH and CHARLES SHEARD

It is often desirable to know the extent to which various kinds of glass will transmit the radiations of different wavelengths which are incident upon them. Luckiesh[1] has recently examined the transmission of certain glasses for ultra-violet radiations and Coblentz[2] has earlier given some curves showing the absorption of a few kinds of glass for the infra-red. It seemed worth while to extend the observations made by these and other investigators to a number of the glasses now in the market under various trade names, in order that those interested in them might have some idea of their transmission, both in the ultra-violet and in the infra-red regions of the spectra.

[1] Luckiesh—Trans. Illum. Eng. Soc. 9, p. 472 (1914).
[2] Coblentz—Investigations of Infra-red Spectra, Part VI, p. 54.

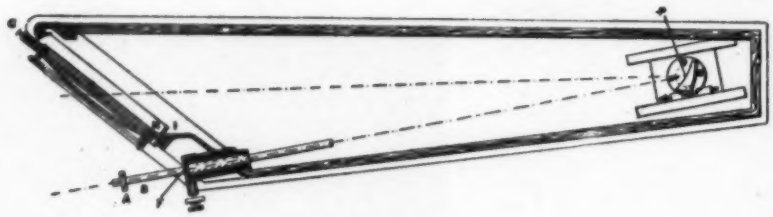

Fig. 1

For the examination of the ultra-violet end of the spectrum, a Fery quartz spectrograph was used. This instrument is shown diagrammatically in Fig. 1. It consists essentially of a quartz prism P silvered on the back. This prism is ground in such a way, that radiation received from a source in front of the slit at A, is brought to a focus at E, after reflection from the back of the prism. The light thus traverses the prism twice, and no lenses are interposed between the source and the photographic plate at E. The prism in this spectragraph performs the functions of both the lenses and the prism in an ordinary spectrograph. There are, therefore, no losses due to absorption other than those which occur in the prism, which of course is very transparent to the ultra-violet end of the spectrum. A condensed spark across two electrodes, one made of iron, the other of an alloy of cadmium, aluminium, magnesium and zinc was used as a source of radiation. This spark gap stood directly in front of the slit of the spectrograph without any condensing lens between it and the slit. A photograph of the spark was first taken. Then the glass to be studied was inserted between the source of radiation and the slit, and a second photograph was taken. The times of exposure were made nearly the same throughout the experiment. The intensity of spark, however, fluctuated so much, that it is not possible to make comparisons concerning the amount absorbed by the different glasses. Besides this the glasses were not all of the same thickness. Hence the relative intensities of different photographs does not give a correct measure of the quantity of radiation absorbed by the glass. It was the purpose of this part of the experiment to show only limits to which these glasses transmit radiations in the ultra-violet end of the spectrum for fairly long exposures. Fig. 2 gives the results of these observations. From these figures it is seen that the amethyst glasses transmit farthest into the ultra-violet. They seem to absorb all wavelengths beyond 0.3091μ. On the other hand, Noviol b transmits least far into the ultra-violet. It absorbs everything beyond about 0.5μ.

	THICKNESS OF GLASS
Condensed Spark	....
Euphos	5.0 mm
Pfund	2.6 mm
Crookes A	3.2 mm
Crookes B	2.8 mm
Noviol b	4.9 mm
Noviol a	4.0 mm
Smoke No. 0	2.3 mm
Smoke No. 1	2.3 mm
Smoke No. 2	2.3 mm
Luxfel	2.4 mm
Oliveye	2.5 mm
Amethyst No. 1	2.6 mm
Amethyst No. 2	4.8 mm
Amethyst No. 3	3.3 mm
Resistal	3.4 mm
Blue No. 0	2.5 mm
Blue No. 1	2.5 mm
Blue No. 2	2.5 mm
First Amber	4.1 mm
Light Amber	2.5 mm
Medium Amber	4.0 mm
Dark Amber	4.3 mm
Dark Amber No. 2	2.3 mm
Light Amber No. 2	2.4 mm
Nactic a	3.4 mm
Nactic 21	3.3 mm
Nactic 22	3.0 mm
Nactic 23	3.2 mm
Nactic 24	3.5 mm

Fig. 2

For the examination of the transmission of these glasses in the infra-red region of the spectrum, a Hilger infra-red spectrometer was used. The essentials of this instrument are shown diagrammatically in Fig. 3. In Fig. 4 is given a photograph of this instrument. Radiation from a Nernst glower falls on the slit S which is .01 inch in width. This radiation from S is received by a concave mirror K by which it is collimated. It then falls on the rock-salt prism P, by which it is dispersed and received on the plane mirror M, and reflected to the concave mirror R. The concave mirror R then focuses the radiation on the slit T, behind which is mounted a Hilger bismuth-silver thermopile which serves as the receiving instrument. The mirrors are made

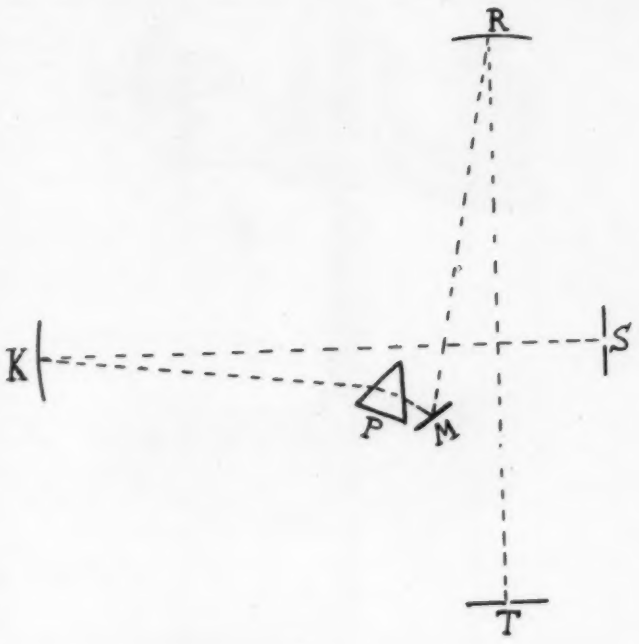

Fig. 3

of nickeled steel. The slit T is also 0.01 inch in width. The prism P and the mirror M are mounted on a table which can be rotated around a vertical axis by means of a fine screw, which is attached to a calibrated drum from which the wavelength under observation can be read directly. By this rotation of the prism P, any desired part of the spectrum can be made to fall on the slit T. The thermopile and the whole instrument were carefully protected from external radiation. With the width of slits used in this experiment, the range of spectrum embraced by the slit at the thermopile was between 0.1μ and 0.26μ. This gives a measure of the purity of the spectrum employed in this work. Two shutters were mounted in front of the slit S. One of these carried the specimen of glass to be studied, the other entirely screened the slit S from the radiation of the Nernst glower. These shutters could be operated by the observer from the position at which he noted the deflection of the galvanometer which was connected to the thermopile.

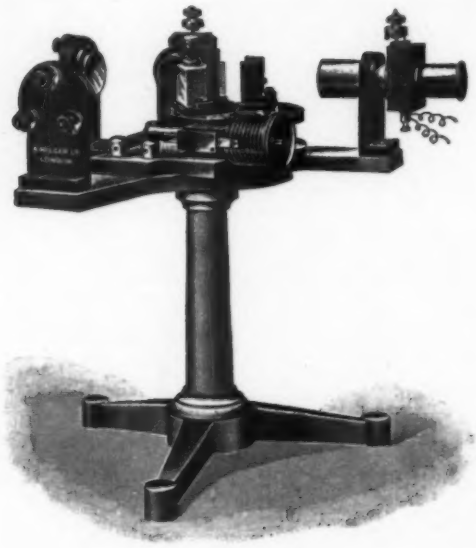

Fig. 4

To get a measure of the energy transmitted by a piece of glass for a particular wave-length, the deflection of the galvanometer, when no absorbing medium was interposed between the Nernst glower and the slit S of the spectrometer, was divided into the corresponding deflection of the galvanometer when the radiation passed through the glass plate before it reached the slit S. In obtaining these deflections, the zero reading of the galvanometer was always taken before and after the deflection was noted. The mean of these two zero positions was used as the true zero position. In this way correction was made for whatever drift in the deflection of the galvanometer might occur during the observations.

The results of these observations have been plotted in the curves shown in Figs. 5, 6 and 7. In these figures, the wavelengths have been plotted on the horizontal axis. On the vertical axis has been plotted the percentage of radiation transmitted. In order to economize space, the vertical axis has been so lettered that the 80% of one curve coincide with 0% of the curve lying immediately above it. This overlapping of the scales should cause no confusion if it is noted that the line marked 80% for one curve is also 0% for the next curve.

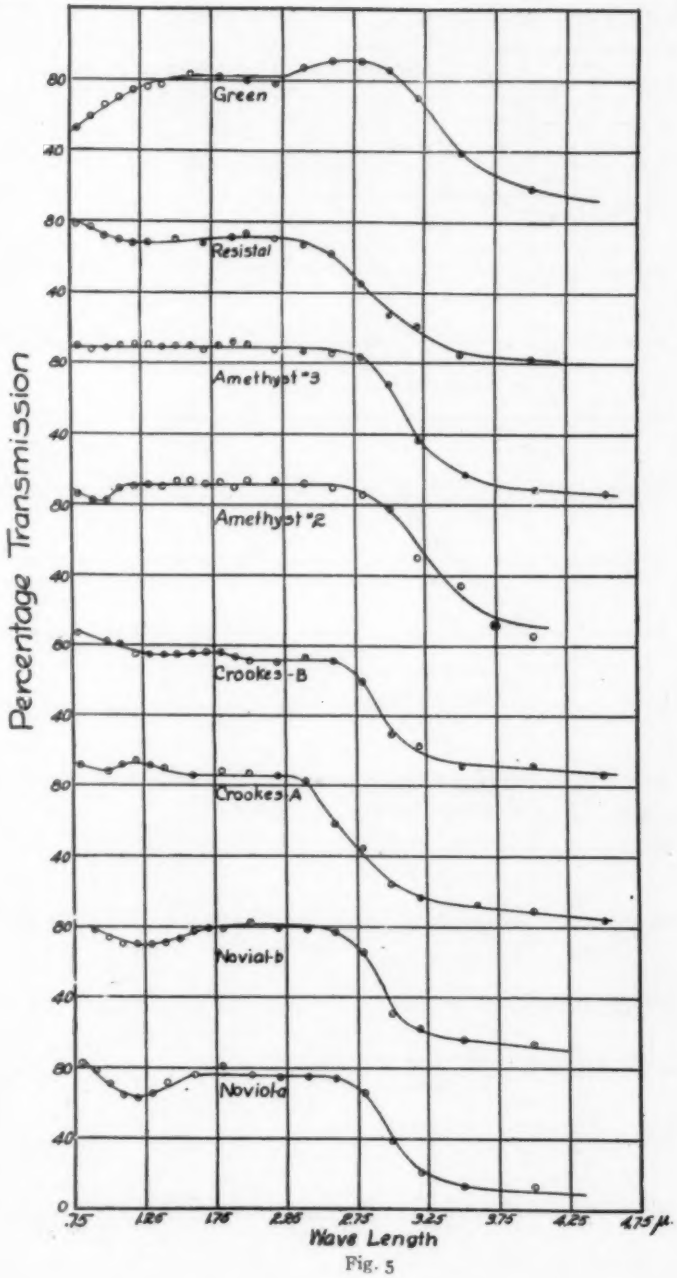
Percentage Transmission
Green
Resistal
Amethyst #3
Amethyst #2
Crookes-B
Crookes-A
Noviol-b
Noviola
80
40
60
0
.75
1.25
1.75
2.25
2.75
3.25
3.75
4.25
4.75 μ.
Wave Length

Fig. 5

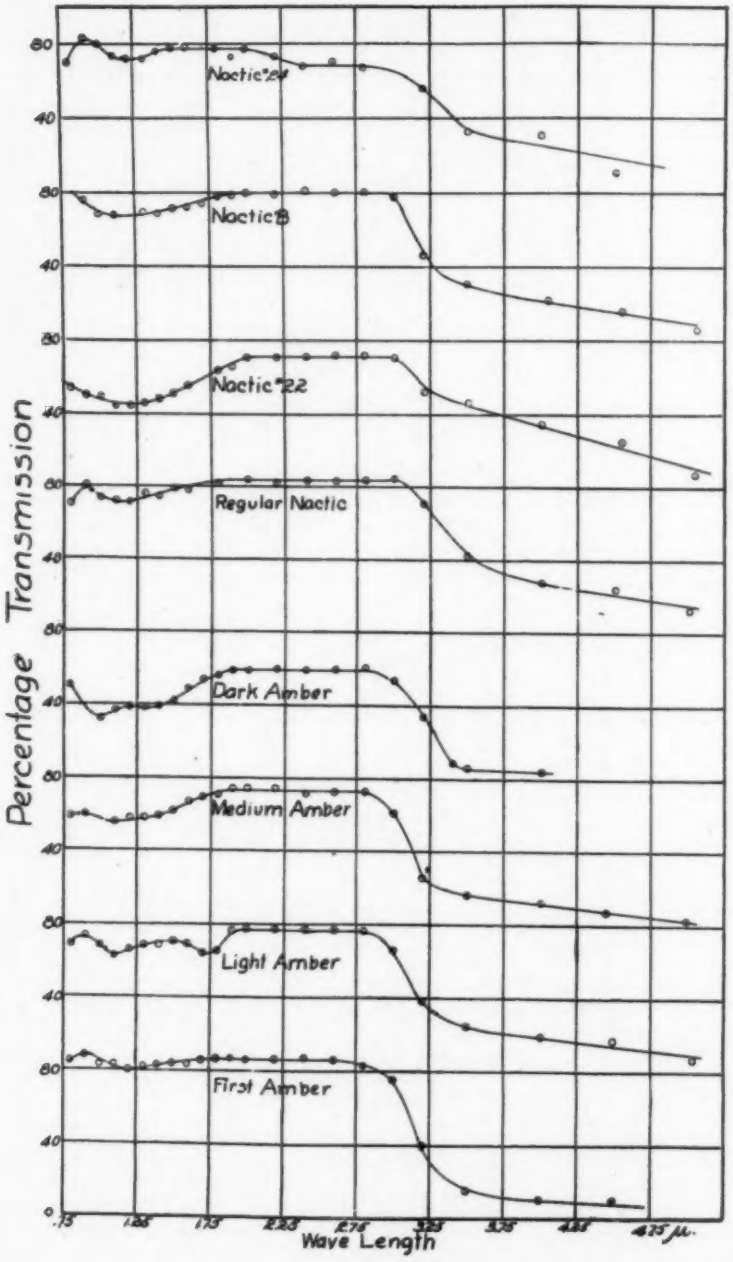
Nactic 24
Nactic B
Nactic 22
Regular Nactic
Dark Amber
Medium Amber
Light Amber
First Amber
Percentage Transmission
80
40
0
.75
1.25
1.75
2.25
2.75
3.25
3.75
4.25
4.75 μ.
Wave Length

Fig. 6

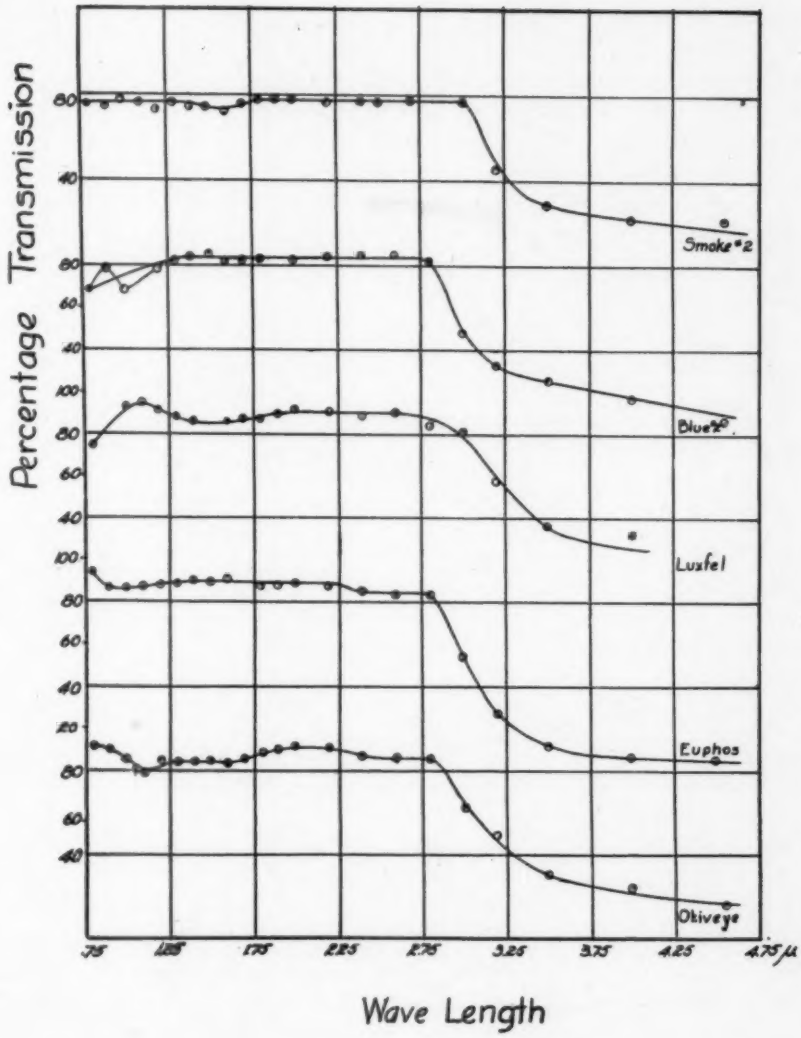
Percentage Transmission
Smoke #2
Blue #
Luxfel
Euphos
Obiveye
.75
1.25
1.75
2.25
2.75
3.25
3.75
4.25
4.75 μ
Wave Length

Fig. 7

From an inspection of these curves, it is seen that beyond 3 μ, these glasses absorb most of the incident radiation. This absorption increases rapidly as the wavelength is increased beyond 3 μ, so that in the neighborhood of 4 μ, the absorption is becoming nearly complete. Near the visible end of the spectrum, many of these glasses show selective absorption to a more or less pronounced degree. In the region of the spectrum, lying very roughly between 1.75 μ and 2.75 μ, there is approximately uniform transmission for most of the glasses studied. The absorption in the Pfund glass in the infra-red for all wavelengths was so large that it was impossible to detect with our apparatus the energy transmitted. So far as the infra-red region of the spectrum is concerned, it absorbs much more than any of the other glasses.

Physical Laboratory
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THE DESIGN OF LENSES FOR AERIAL PHOTOGRAPHY

By C. W. FREDERICK

It is not the object of this paper to suggest anything new or good in lens design, nor to propose desirable modifications to fulfil the requirements of aerial photography, but merely to describe the lenses we have actually produced in the face of wartime difficulties. When the European war broke out, the supply of glass from France and England was cut off, and American manufacturers succeeded only in producing those glasses suitable for visual instruments, such as binoculars and gunsights, but failed completely to produce the dense barium crown required in high-grade photographic objectives. Thus we were confronted with the problem of making a lens of these very unsuitable materials, a problem not unlike that of making something out of nothing, and altogether discouraging to contemplate.

But first, and, as it proved, even more difficult was the necessity of finding out what was wanted in aerial photography. There was no use in guessing, for even a good guess was certain not to coincide with the ideas of others; the only thing was to find out what was actually being done. But until the United States entered the war and for a time afterward the developments in aerial photography were carefully hidden behind a military veil through which at least some of us in America could not see; and for a long time all our efforts were futile to get at the simple but necessary details as to

lens speed, focal length, and the size of the picture to be covered. First we heard the French were using a lens of speed *f*:6.0, but nothing as to focal length or picture. The only two glasses then available at home, actually being manufactured, not merely promised, were baryta flint and dense flint. With these we tried to make a *f*:6.0 lens. But though we succeeded in working out several good anastigmat lenses of less speed, we failed to get a *f*:6.0 lens.

About this time we obtained the first definite information as to what the British army was doing. They were using a lens of relative aperture *f*:4.5 with color screens, focal length 8.5 inches, and covering a plate 4 inches by 5 inches. Also from another source we were given to understand that barium glass might soon be had from abroad. Thus for the first time, we had a solid foundation with which to make a start. Selecting not the most suitable glass, but that most likely to be produced, we began work on our first *f*:4.5 lens, which was of the four-piece, air-spaced type.

Since these lenses were to be used with color screens which would cut out the violet light, the color curve of the lens was modified to favor the visual portion of the spectrum allowing the violet light to stray. The actual adjustment was such as to make the focal length of the lens for the yellow sodium or D line of the spectrum the same as that for the hydrogen blue or G′ line of the spectrum.

Another departure from the usual type of photographic lens was suggested by the relatively small area of the plate to be covered. In most lenses of the anastigmat type there is a region well out from the center of the picture where the lens gives images free from astigmatism, and where, if the lens has no coma, the image of a point source of light is as round and perfect as that formed in the center of the picture. Usually this region is from 23° to 26° from the optical axis of the lens, and in the case of aeroplane cameras, it is well beyond the limits of the plate. Therefore a change was made to throw the point of no astigmatism nearer to the optical axis and within the area of the picture. Other advantages were also gained by this change; it made possible a better correction for spherical aberration, and led to a form which was less sensitive to mechanical imperfection in manufacture. The latter is an important advantage in the hurry of war work.

The adjustment for spherical aberration, and even color, is not of very great importance as affecting definition. The image of a point source of light in the optical axis of a reasonably well-made lens is always too good,

and it is a mere waste of time to split hairs over this correction. It is practically impossible to focus a lens correctly, especially in the case of aeroplane cameras which are subject to changes of temperature and rough handling, so we never really get the benefit of the central definition that exists in the lens, and it is not likely that the aberration could be so bad as to affect greatly the out of focus image. The actual adjustment for spherical aberration was such that, for a lens of 100 mm focal length, the extreme ray or that traversing the lens at *f*:4.5 would strike the optical axis at a point 0.4 mm beyond the focal plane, and a ray traversing the lens at *f*:6.3 would strike that axis 0.4 mm short of the focal plane. However, the actual image formed was always much smaller than this adjustment would indicate.

Coma, like spherical aberration, need only be reasonably well eliminated; the presence of a little coma is sometimes beneficial rather than injurious. However, since it was easy to do in a four-piece air-spaced lens, the sine condition was satisfied within 0.03 mm for all rays.

Distortion is important. When the lens is used for mapping it is necessary that all parts of the picture should maintain their proper relations to one another in order that their corresponding points may be accurately located on the ground. In our lens, this correction was reduced to less than 0.01 mm at the extreme corner of the plate.

But the most difficult, and the most important of all the corrections of a lens is *astigmatism*. The quality of the lens depends upon the magnitude of its astigmatism. If we image the diagram of a lens in longitudinal section, with oblique rays of light traced through it, we should expect them to come to a focus at some point dependent on the components of curvature encountered in their passage through the elements of the lens. This is called the primary focus. But if we think of the rays in a plane perpendicular to the plane of the diagram, we may easily expect them to encounter different components of curvature and therefore to be brought to a different focus. This is called the secondary focus. Thus the rays of light emanating from a distant point source will not be brought to a point image. The best image or nearest approach to a point will lie somewhere between these two focal points, and it will usually be quadrilateral in form. The nearer the focal points are to each other, the smaller the best image will be. And when we speak of astigmatism, we are usually thinking of the distance from one focal point to the other, and thus indirectly of the size of the best image which controls the definition of the lens. The great problem in lens design-

ing is to reduce the astigmatism to the lowest possible limits and to make the best images for all oblique rays fall upon the focal plane. In our first lens, we managed to keep the best images upon the focal plane within two-tenths of one per cent of the focal length, and the maximum astigmatism was seven-tenths of one percent of the focal length. The properties of this lens are shown in the diagram (Fig. 1). These are actual measurements on a manufactured lens, not the theoretical properties. It was finally manufactured as a 10-inch lens instead of 8.5 inches focal length as originally intended.

Before we had completed the computations on the *f*:4.5 lens a call came for the *f*:6.0 lens; it was wanted with a focal length of 20 inches, and wanted right away. It happened that one of the Kodak lenses we were manufacturing in smaller sizes had all the requirements for an aviation lens, except it covered a larger picture than necessary, and gave a slightly inward curving field when the astigmtism was pinched to the required amount. But since we did not have time to recompute it, the formula was multiplied up to give a focal length of 20 inches, and used without other changes than those which could be effected by varying the air spaces as required in adjusting the individual lenses in the course of manufacture. The properties of this lens as measured from an actual manufactured objective are shown in Fig. 2.

This lens was afterward recomputed to work at *f*:5.6 and its astigmatism reduced to less than seven-tenths of one per cent. of the focal length. But the war ended before a first sample could be made.

After finishing the 10-inch *f*:4.5 lens, though we still kept to the four-piece air-spaced type of lens, radical changes were made in the form of the components, the result being a lens in which the maximum astigmatism was less than five-tenths of one per cent. The first sample of this lens was not finished until after the armistice had been signed, and the lens was never manufactured, although it was remarkably fine. Its properties are shown in Fig. 3.

Another *f*:4.5 formula was computed with light barium crown and light flint, two glasses which were being manufactured in America, but through a misunderstanding as to the properties of the glass, the formula had to be recomputed, and the change led to awkward forms that were hard to get over, and the formula was only finished as the war ended. It was not very good, as the maximum astigmatism was about eight-tenths of one per cent., too much for a first-class *f*:4.5 lens.

Another very interesting lens was one of 48 inches focal length. A speed of only *f*:8.8 could be obtained with the largest discs of glass that could be obtained. The formula was a modification of the Kodak anastigmat *f*:7.7 formula, in which the components were made thinner to reduce the weight of glass in so large a lens; also the length over all was increased to flatten the aberration curve so that the same formula could be used at different apertures, as the latter would vary with the size of glass discs that could be obtained. The spherical aberration was so good that the lens would have worked at any aperture up to *f*:7.0. Also the field was so small, only seven and a half degrees, so that astigmatism was not a problem.

The lenses that were actually manufactured in quantity were the 10-in. *f*:4.5 lenses, and the 20-in. *f*:6.0. When these were mounted according to the formula they were found to vary in focal length more than allowable, and the spherical aberration and astigmatism were variable and never quite right. But here is the great advantage of a four-piece airspaced type of lens. The focal length, spherical aberration, astigmatism, and distortion can all be adjusted independently by changing the air-spacing of the components. All the aviation lenses manufactured by us were individually measured and adjusted upon the lens bench. The spherical aberration was adjusted by observing the central image, and this could always be made better than theory. Astigmatism was adjusted to the theoretical amount demanded by the formula. Distortion was never much out, and I believe it was never necessary to correct it.

Although we only manufactured two types of lenses we had formulae ready for four others, and they would have immediately gone into work if the end of the war had not brought things to a sudden stop. However, the labor directly expended to bring these six forms to final completion was only a small fraction of the total work done in the search for them. Many promising leads proved absolute failures, and many very good theoretical lenses had to be discarded because they were mechanically impossible or sometimes because they might have been awkward or troublesome to manufacture. In lens making as in everything else it is hard to make theory and practice agree, and at least three-fourths of our effort was expended to reconcile these two antagonistic and dictatorial taskmasters.

Research Laboratory
EASTMAN KODAK COMPANY
Rochester, N. Y.
December, 1918

THE MEASUREMENT OF REFLECTION AND TRANSMISSION FACTORS

By M. LUCKIESH

Little has been done toward standardizing the determination of reflection and transmission factors, but owing to the fact that there are a number of conditions which influence such measurements this should be done. These values are ordinarily presented with such nonchalance that one is led to conclude there is a general belief that they are fixed and invariable quantities possessed by the surfaces or media for which they have been determined. In two papers [1] dealing respectively with the two quantities it has been the aim to show the conditions which influence the results and to determine the methods which should be standardized for such measurements. It is the aim of this paper to review the problems briefly and to propose a standardization of methods.

REFLECTION FACTOR

Surfaces generally reflect light both specularly and diffusely; that is, they are usually far from perfect mirrors or perfect diffusers. Assuming the general surface, the following are the chief factors which influence the value determined by measurement:

1. *Character of the reflecting surface.*

   It is not unusual to determine the reflection factor by comparing the brightness of the surface with that of a surface of known reflection factor under the same intensity of illumination. If the surface is highly glazed it is obvious that the brightness will be made up of that due to diffuse reflection and that due to a more or less perfect image of the light-source or of other luminous objects mirrored in the glazed surface. The "specular brightness" of the surface varies with the brightness of the light-source or other mirrored object, whereas the "diffuse brightness" depends upon the *intensity of illumination*. Hence specular reflection may introduce a spurious quantity into the determination of reflection factor. The values of reflection factor for a given surface as determined in this manner may differ considerably, due to variation in the brightness of the source of illumination.

[1] M. Luckiesh, Measurement of Reflection-Factor, Elec. World, May 19, 1917. M. Luckiesh and L. L. Mellor, Measurement of Transmission-Factor, Jour. Frank. Inst. 186, 1918, p. 529.

2. *Location of the source of illumination.*

If the light-source is so located that light is specularly reflected into the photometer which is used for making a comparison of the brightnesses of the specimen with that of a standard surface, the difficulty described in the preceding paragraph will be encountered. In the case of glossy surfaces, slight changes in the position of the photometer, of the light-source, or of the surface may alter the brightness determination considerably, and it is obvious that different values of reflection factor will be obtained. Each value is correct for the specific conditions, but a statement of conditions is necessary. Therefore it is desirable to have conditions which are easily described and reproduced.

3. *Solid-angular extent of the light-source.*

As already stated the specularly reflected image will vary, for a given surface, with the brightness of the light-source. The latter can vary widely and still the illumination, and also the component of brightness due to diffusely reflected light, may remain constant.

4. *Spectral character of the illuminant.*

It is not uncommon to have the reflection-factors of colored surfaces, such as wall-papers and paints, presented without specifying the illuminant. The reflection factor of a colored surface may vary as much as 50% for the illuminants ordinarily encountered. The illuminant should always be specified sufficiently so that the spectral distribution of energy is indicated.

5. *The method of photometry.*

In the case of considerable differences in color, the two chief methods of photometry, namely the direct-comparison and the flicker methods, will yield different results. This is one of the most annoying aspects, but in the absence of standardization, the method of photometry should be specified, and other conditions such as the size of the photometric field and the approximate absolute brightness should be recorded. Perhaps the flicker photometer should be generally standardized for the measurement of reflection and transmission factors owing to the better reproducibility of measurements by this method. However, there are still many unsettled questions pertaining to color photometry.

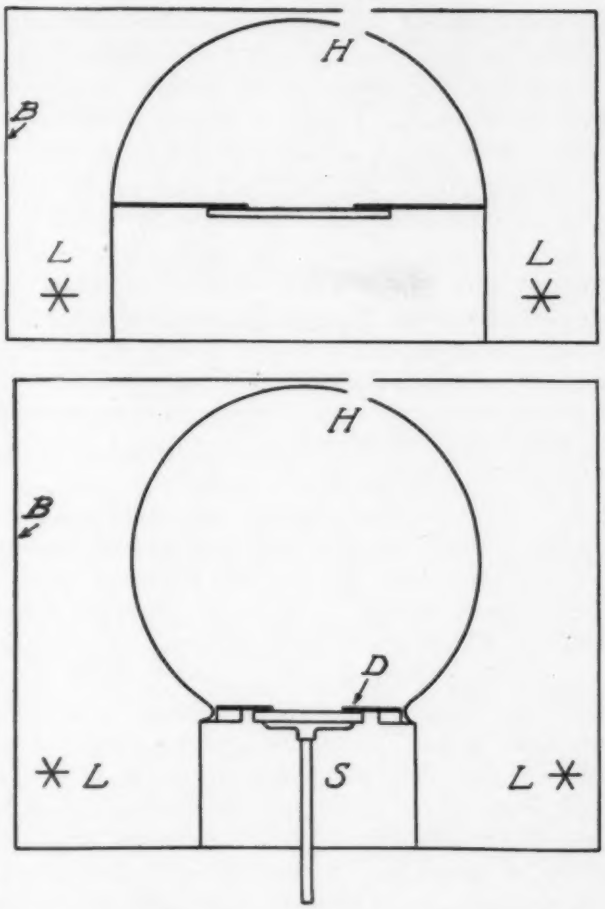

Fig. 1—Apparatus for determining reflection-factors of specimens diffusely illuminated.

In general these influences can not be avoided, but the method selected for standardization should be one which is equitable and easily described, and one which represents fairly well the conditions under which the reflection factor of the surface is of interest in its practical use. Generally we are concerned with the reflection factor of the surface as a whole, that is, a sort of weighted mean of the reflection factors for all directions. In case a more intimate analysis of the reflecting characteristic of the surface is desired, a reflection-factor curve for all angles may be determined.

It appears that perfectly diffused illumination best meets the requirements for determining the reflection factor of a surface as a whole. In other words the light-source should be of uniform brightness and should subtend an entire hemisphere. A paint or wall-paper in actual use receives light from many directions and seldom is its reflection factor for a certain direction or angle of interest. Except in the case of glossy surfaces of low reflection factor the amount of light specularly reflected is much smaller than that which is diffusely reflected. By using perfectly diffuse illumination the specular brightness is not permitted to contribute disproportionately to the total brightness. If a narrow beam of light is used and the photometer is placed in a position to avoid specular reflection the specularly reflected component is entirely eliminated, which obviously is unjust unless only the diffuse reflection factor is desired. These questions arise, for example, in comparing the reflection factors of paints and a difference of a few per cent may do an injustice to some samples.

The Nutting reflectometer in which is employed the practical equivalent of two paralled surfaces of infinite extent and of uniform brightness, meets the foregoing suggestion; that is, the illumination of the specimen whose reflection factor is desired is practically perfectly diffuse, the light-source subtending in effect an entire hemisphere. The Martens polarization photometer, which Nutting originally used with his ingenious device, could be replaced by some other compact optical instrument. Ordinary photometers are more generally available, and it is easy to provide a simple apparatus similar to one of those illustrated in Fig. 1 for the purpose of obtaining diffuse illumination. A dense opal glass globe or hemispherical shell is provided with a hole (H) and placed as shown in a box (B) painted white. A number of lamps (L) are symmetrically located on the bottom of the box. The samples to be tested are pressed upward against a thin metal diaphragm (D) with a suitable aperture in it. The hole (H) should be offset somewhat in order to avoid reflecting an image of it or of the nose of the photometer into the photometric field. These two devices have been used successfully and the results obtained check well with those determined with the Nutting reflectometer. In using the devices illustrated in Fig. 1, it is obvious that a surface of known reflection factor should be available so that the reflection factors of the specimens may be obtained by a direct comparison of brightnesses. The reflection factor of the standard may be determined by means of the Nutting reflectometer which yields absolute

values, or if it is a perfectly diffusely reflecting surface the simple relation between illumination and brightness can be utilized. White blotting paper or sandblasted opal glass are satisfactory working standards.

The integrating sphere can be utilized for determining the reflection factors of reflecting surfaces by placing the latter inside the sphere and permitting a beam of light to enter and illuminate the reflecting surface. A suitable arrangement of the various details presents no difficulties.

TRANSMISSION FACTOR

Similar influences bear upon the results of the determination of transmission factors as of reflection factors, but there is another point to be considered which does not apply to reflecting surfaces, namely,

6. *The transmission factor depends, in the case of one side of the specimen being rough, upon the direction in which the light passes through it.*

> For example, the transmission factor is generally smaller when the smooth surface faces the light-source than when the rough side faces the light-source, other conditions remaining equal. This difference is greatest for a narrow beam of light and diminishes as the illumination becomes more diffuse, usually disappearing when the illumination has become perfectly diffuse.

Some of these differences are shown in the accompanying table for flat crystal glass specimens smooth on one side. Specimen 5 was a sheet of clear glass with one side sand-blasted; specimen 7 was a sheet of clear glass etched with acid on one side; specimen 8 was a common "pebbled" glass, smooth on one side; the remaining specimens contained ribs on one side the other side being smooth. For further details, reference should be made to the original paper. It is seen that the transmission factor is different for a narrow beam of light at perpendicular incidence than for diffuse illumination. The ratio of the transmission factor for a narrow beam to that for diffuse illumination is given in the last column for each case. In general it appears best to employ perfectly diffuse illumination for the determination of transmission factors and this can be done by an arrangement of apparatus similar to that illustrated in Fig. 2. H is a hemispherical shell of opal glass; L are light-sources, located symmetrically with respect to H; O is an opening into a small intergrating sphere 15 inches in diameter; T is a target, painted white on both sides; B is a box, painted white inside; and the photometer is placed underneath. The specimen to be tested is placed over O, just under

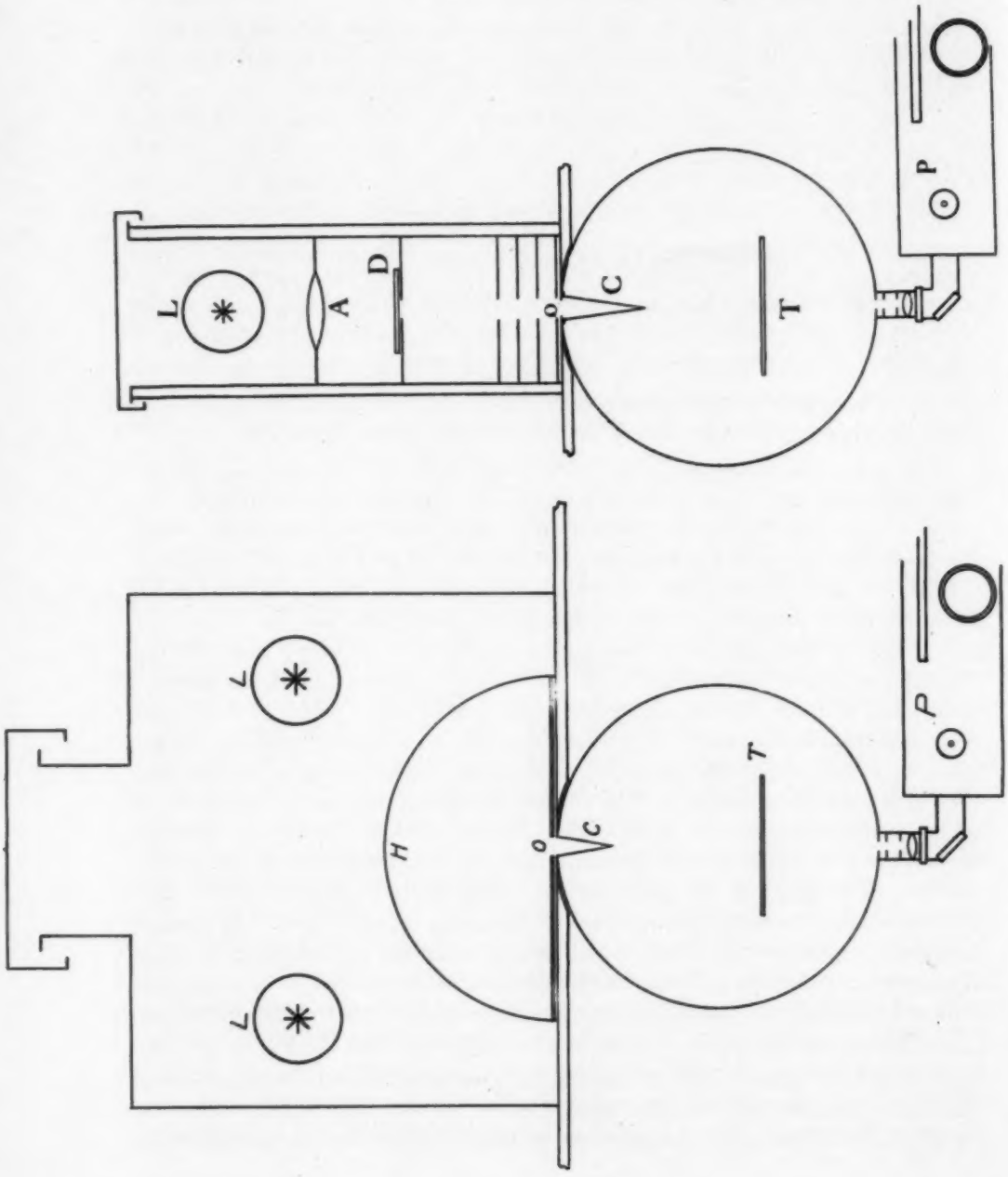

Fig. 3—Apparatus for determining transmission-factors of specimens illuminated by a narrow beam at normal incidence.

Fig. 2—Apparatus for determining transmission-factors of specimens diffusely illuminated.

a thin diaphragm with a hole in it. Provision should be made for having the two sides of the specimen in contact with the diaphragm and O respectively. A disadvantage of this scheme is the great amount of light required.

In case a narrow pencil of light is desired, the apparatus shown diagrammatically in Fig. 3 is satisfactory. L is a single powerful light source; A a lens; and D a sheet of clear glass, etched on one side. C is a slender, hollow cone of clear glass, acid etched on its exterior. An extensive investigation indicated the necessity of such a device for the purpose of partially diffusing the light entering the sphere. Satisfactory proof was obtained that this cone did not introduce any error of measurable magnitude. If the transmission, characteristic of a specimen is desired, the sphere and cone may be removed, and the relative intensity of transmitted light may be determined for the angles desired. Obviously other modifications of the integrating sphere can be utilized.

TRANSMISSION FACTORS FOR CRYSTAL GLASSES UNDER VARIOUS CONDITIONS

Specimen of glass	Side toward light source	Transmission Factor		Ratio $\frac{\text{diffuse}}{\text{direct}}$
		Narrow beam	Perfectly diffuse	
5. Sand blasted.....	Rough	0.783	0.702	0.897
" "	Smooth	.739	.695	.940
7. Etched.....	Rough	.794	.709	.893
"	Smooth	.758	.704	.929
8. Peddled.....	Rough	.846	.746	.882
"	Smooth	.790	.746	.944
10. Coarse ribbed.....	Ribbed	.766	.617	.805
" "	Smooth	.515	.616	1.196
11. Fine ribbed.....	Ribbed	.858	.793	.924
" "	Smooth	.790	.791	1.001
12. Wavy ribbed.....	Ribbed	.884	.822	.929
" "	Smooth	.860	.821	.955

SUMMARY

The aims of this paper are to indicate the conditions which influence the results of determinations of reflection and transmission factors; to indicate the desirability of standard methods; and to recommend such standard methods. In general it is recommended that reflection and transmission factors be determined for diffuse illumination; that is, that a light-source of uniform brightness subtending a hemispherical angle should be used.

Nela Research Laboratory
NATIONAL LAMP WORKS OF GENERAL ELECTRIC CO.
December 2, 1918.

specimens illuminated by a narrow beam at normal incidence.

specimens diffusely illuminated.

Fig. 2—Apparatus for determining

CONSTITUTION OF THE OPTICAL SOCIETY OF AMERICA

ARTICLE I.—NAME

The name of this society shall be THE OPTICAL SOCIETY OF AMERICA.

ARTICLE II.—AIM AND PURPOSE

It is the aim and purpose of this society to increase and diffuse the knowledge of optics, to promote the mutual interests of investigators of optical problems, of designers, manufacturers and users of optical instruments and apparatus of all kinds and to encourage co-operation among them.

ARTICLE III.—OFFICERS

The officers of this society shall be a president, a vice-president, a treasurer, a secretary, and an executive council consisting of the above named officers of the society, the retiring president of the society and four members at large.

ARTICLE IV.—MEMBERSHIP

Membership in the society shall be either honorary, regular or associate. Associate members may be either individuals or corporations.

ARTICLE V.—AMENDMENTS

This constitution shall be amended when the proposed amendment is favored by four-fifths of all the members voting upon it. A copy of every proposed amendment shall be mailed to each regular member of the society at least thirty days before a vote is taken. Voting shall be by ballot.

AMENDMENTS TO THE CONSTITUTION

1. The editor of the Journal shall be, *ex officio*, a member of the Executive Council.

BY-LAWS

I.—MEMBERSHIP

SECTION 1. Eligibility. Any person who has, in the opinion of the Council, contributed materially to the advancement of optics shall be eligible to regular membership in the society. Any person or corporation interested in optics is eligible to associate membership. Any person who has done eminent service in the advancement of optics is eligible to honorary membership.

SEC. 2. Application for Membership. Applications for membership in this society will be received when stating the candidate's name and qualifications for membership in the society, and when signed by two members of the society.

SEC. 3. Election to Membership. Applicants shall be admitted to membership in the society when admission is favored by two-thirds of the members of the Council by vote. The Council may elect honorary members by unanimous vote.

SEC. 4. Duties and Privileges. All regular members shall have the right to vote at elections, hold office, attend meetings and receive the official publications of the society. Associate members shall have similar privileges except that they may not vote at elections nor hold office in the society. Honorary members have all the privileges of regular members but need not pay dues.

SEC. 5. Termination of Membership. Membership in the society may be terminated or the names of the members may be placed upon the non-resident list by vote of the Council. Failure to pay dues for one year shall be deemed sufficient cause for termination of membership.

II.—Collections and Disbursements

Section 1. Dues. All regular and associate individual members of the society shall contribute five dollars annually and corporation members fifty dollars annually toward the expenses of the society. Individual members may become life members by the payment of fifty dollars. The payment of one thousand dollars or more toward the expenses of the society by any corporation or individual entitles them to the rank of patron of the society.

Sec. 2. Disbursements. Disbursements and assessments shall be made only when recommended by the treasurer and favored by two-thirds vote of the Council. No officer nor any members of the society shall receive any remuneration for his services to the society.

III.—Officers

Section 1. Regular Officers. The duties of the president, vice-president, treasurer and secretary of the society shall be the usual ones performed by such officers.

Sec. 2. Executive Council. The Executive Council shall direct all affairs and activities of the society not otherwise provided for by the Constitution as well as perform those duties specifically assigned to it.

Sec. 3. Committees. The president shall appoint, with the approval of the Council, such committees as may further the objects of the society, including a committee on Publications, and one or more committees on Progress. The treasurer, the secretary and the chairmen of the various committees shall make formal reports to the society at least once each year.

IV.—Election of Officers

Section 1. Eligibility. Officers shall be elected from among the regular and honorary members of the society. The president of the society shall not be eligible for election to a second consecutive term. No officer of the society shall be eligible to hold the same office for more than two years in succession.

Sec. 2. Time of Election. All officers shall be elected annually in October of each year, and shall hold office during the calendar year following the election.

Sec. 3. Mode of Election. Election shall be by ballot and shall be by the primary system. The two persons receiving the highest number of votes cast for any office in the primary shall be placed in nomination for regular election. In any primary, if no nominee receives twenty per cent. of the votes cast, nomination shall be made by the Council.

V.—Publications

This society shall publish a journal devoted to the advancement of optics. The editor-in-chief of the journal and six or more associate editors shall be elected by the Executive Council of the society. Every regular, honorary and associate member of the society shall be entitled to receive the journal.

VI.—Local Sections

Local sections of the society may be formed in any locality, with the advice and consent of the Council, for the purpose of holding meetings and promoting co-operation. The affairs of such local sections shall be entirely in their own hands.

VII.—Meetings

General meetings of the society shall be held as decided upon by the Executive Council.

VIII—Revision of the By-Laws

After recommendation by the Council, By-Laws may be enacted, amended or suspended by a two-thirds vote, by ballot, of the regular members of the society.

OFFICERS AND COMMITTEES 1919

Officers

President, Fred E. Wright
Vice-President, F. K. Richtmyer
Secretary, P. G. Nutting
Treasurer, Adolph Lomb

Executive Council

The above officers, the editor-in-chief of the Journal, and
J. P. C. Southall W. B. Lancaster
L. T. Troland Herbert E. Ives

Editors of the Journal

H. Kellner, *Editor-in-Chief*
J. A. Anderson, *Astronomical and Cosmical Optics*
Herbert E. Ives, *Photometry, Radiometry and Spectroradiometry*
W. B. Lancaster, *Ophthalmology*
C. E. K. Mees, *Photography*
P. G. Nutting, *Illuminating Engineering Optics and Pyrometry*
F. K. Richtmyer, *Physical Optics*
J. P. C. Southall, *Geometrical Optics*
Fred E. Wright, *Crystal Optics and Polarimetry*

Committee on Finance

Adolph Lomb Norman Macbeth
C. H. Kerr Marshall D. Ewell
Geo. S. Crampton

Committee on Meetings and Papers

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